ACOUSTIC AND DURABILITY PERFORMANCES OF *ARENGA PINNATA* PANEL

LINDAWATI ISMAIL

A thesis submitted in
fulfillment of the requirements for the award of the
Degree of Master of Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
Universiti of Tun Hussein Onn Malaysia

FEBRUARY 2012

Dedicated To My Beloved Parents

ACKNOWLEDGEMENT

First of all, I would like to thanks to Allah who has given me health and millions idea during doing my research. I would like to express my thanks to Prof. Mohd. Imran Ghazali, Dr. Shahruddin Mahzan, and Ass. Prof. Ahmad Mujahid Ahmad Zaidi for the inspirational supervision, guidance and time during this project.

In addition, I would like to thank to everyone in the Mechanical and Manufacturing Engineering at the University of Tun Hussein Onn Malaysia for their continual support, encouragement and suggestions with particular thanks to all technicians of Laboratory: Ceramic and Polymer, Noise and Vibration, and Air Conditioner, for their practical suggestions and willingness to offer help whenever it was needed.

Thanks to all supported friends; Noorasyida Arshad, Amilia, Hasbullah, Nurbaity Aqmar Mahamud, Siti Nur Hidayah, Bapak Fuadi Noor Balia, Bapak Madi Hermadi, Bapak Bambang Basuno, Ibu Yeni Suzanti, Ibu Sadariah, and Bapak Arhami. For last but never least, I thank to my wonderful parents for their love and endless support given to me.

ABSTRACT

This study aims to investigate the feasibility of *Arenga Pinnata* fiber to be applied for acoustical material component. There different binders namely polyurethane, urea formaldehyde and latex were employed as binder. The weight percentages of binder used were 10%, 15%, 20%, 25%, and 30%. Hand layup process was used in specimens production. The physical, acoustical and durability properties of the panels were investigated experimentally. The result shows that panel with high percentages of binder tends to have high density and tortuosity, but less porosity. The optimum porosity of 0.94 was obtained from panel that added with 10% Latex. In general, *Arenga Pinnata* panels show good sound absorption from mid to high frequency that is from 2000 Hz to 5000 Hz. The best sound absorption is performed by panel added with 10 % Latex with a maximum absorption coefficient (α) of 0.96 at 3000 Hz. The average Noise Reduction Coefficient (NRC) for all panels is 0.40. The value indicates that *Arenga Pinnata* panels are highly absorptive material. However, *Arenga Pinnata* panel is poor insulator since the optimum sound transmission loss (STL) is only 9.37 dB from panel added with 15% polyurethane at 5000 Hz. Thus, *Arenga Pinnata* panel is applicable to reduce echo caused by reflection effects within a room. Sound absorption increases as porosity increase and decrease as density-tortuosity increase. Hence, *Arenga pinnata* fiber is applicable for acoustical component panel. Moreover, *Arenga Pinnata* panels are durable that resist in water, heat, and fire. It is applicable for heat insulation.

ABSTRAK

Kajian ini bertujuan untuk mengkaji kebolehgunaan serat *Arenga Pinnata* sebagai komponen bahan akustik. Tiga pengikat yang berbeza telah digunakan sebagai pengikat serat iaitu polyurethane, urea formaldehid dan latex. Peratus berat pengikat yang digunakan dalam kajian ini adalah 10%, 15%, 20%, 25%, dan 30%. Spesimen kajian dihasilkan dengan menggunakan proses gelekan tangan. Sifat-sifat fizikal, akustikal dan ketahanan panel spesimen telah dikaji secara ujikaji. Hasil kajian menunjukkan bahawa panel yang mempunyai peratus berat pengikat paling tinggi mempunyai ketumpatan dan ketidaklurusan liang yang tinggi tetapi keliangannya kurang . Keliangan yang optimum, 0.94 diperolehi dari panel yang dicampur dengan 10% Latex. Pada umumnya, *Arenga Pinnata* mempunyai ciri-ciri penyerapan bunyi yang baik dari frekuensi pertengahan ke frequency tinggi, ia itu dari 2000 Hz hingga 5000 Hz. Penyerapan bunyi yang paling baik diperolehi dari panel yang dicampur dengan 10% Latex, di mana pekali penyerapan maksimum (α) adalah 0.96 pada 3000 Hz. Nilai purata pekali pengurangan bunyi (NRC) semua panel spesimen ialah 0.40. Nilai ini menunjukkan bahawa panel-panel *Arenga Pinnata* adalah merupakan bahan penyerap bunyi yang baik. Bagaimana pun, panel *Arenga Pinnata* didapati merupakan penebat yang tidak baik kerana kehilangan hantaran bunyi yang optimum (STL) hanyalah 9.37 dB diperolehi dari panel yang dicampur dengan 15% polyurethane pada 5000 Hz. Oleh kerana itu, panel *Arenga Pinnata* sesuai digunakan untuk mengurangi gema di dalam bilik. Penyerapan bunyi di dapati meningkat dengan meningkatnya keliangan dan berkurang dengan meningkatnya ketumpatan - ketidaklurusan liang. Oleh itu, Serat *Arenga Pinnata* didapati boleh digunakan sebagai panel komponen akustik. Selain dari itu, panel *Arenga Pinnata* juga adalah tahan lasak yang boleh merintangi air, haba dan api. Ianya sesuai digunakan sebagai penebat haba.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

α	-	Sound Absorption Coefficient
α_∞	-	Tortuosity
ß	-	Beta Ray
γ	-	Gamma Ray
λ	-	Wavelength
μ	-	Miu
ρ	-	Density
□	-	Porosity
τ	-	Sound Transmission Coefficient
A	-	Cross-sectional Area
c	-	Speed of sound
C	-	Celcius
Co	-	Cobalt
d	-	Diameter
dB	-	Decibel
f	-	Frequency
g	-	Gram
GPa	-	Giga Pascal
Hz	-	Hertz
I_i	-	Sound Incident Wave
I_α	-	Sound Absorbed Wave
Inc.	-	Inch
k	-	Thermal Conductivity
K	-	Kelvin
l	-	Length
L	-	Sound Level
m	-	Meter

mm	-	Millimeter
MPa	-	Mega Pascal
q	-	Heat Conduction
s	-	Second
T_{60}	-	Reverberation Time
V_a	-	Air Voids
V_m	-	Total Volume of The Sample
Sr	-	Strontium
W	-	Watt
ASTM	-	American Society of Testing and Material
ISO	-	International Standard Organization
ITM	-	Impedance Tube Method
NRC	-	Noise Reduction Coefficient
PU	-	Polyurethane
STC	-	Sound Transmission Class
STL	-	Sound Transmission Loss
TF	-	Transfer Function
UL	-	Underwrite Laboratory
UF	-	Urea Formaldehyde
VBT	-	Vertical Burning Test

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

The increase in population has consequently contributed in increasing the noise problem of the world, recently. Noise as undesirable sound is involved in one of the most dangerous pollution. Expansion of modern industrial operation and transportation such as aircraft, train, cars or buses are the main causes of noise problem in urban areas. In addition, human daily activities have great contribution in generating noise levels that can annoy to other people.

The effect of noise on people have been widely published, whether physiological or psychological effects (Atmaca *et al.*, 2005). The psychological effect is related to emotional annoyance, e.g. eager, insomnia, fear, and stress (Saeki *et al.*, 2004). The physiological effect is related to human body, e.g. hypertension, cardiac disease, colitis, headache, dizziness, and the worst are hearing loss (Blomkvist *et al.*, 2005). Both psychological and physiological effects have been hypothesized caused by high noise level exposure in a long period. Owing to the risk affected on people, noise control is highly required to create acoustically pleasing environment. Noise cannot be destroyed but it can be broken down into acceptable level for human ear.

In any circumstances, noise may be controlled at any of these elements: source, path, and receiver, as listed in Table 1.1. It is essential to treat at least one of these elements. The source is the element that directly responsible for sound generation. The path covers sound propagation media such as air, water or solid material, in where sound wave reacts with as they travel from the source to the receiver (Hansen and Goelzer, 2006). Here, the receiver is where all the sound generated was received.

Table 1.1: Noise Control Approaches at Source-Path-Receiver (Rossing, 2007)

Control at the source	Control in the path	Control at the receiver
Maintenance	Enclosure	Relocate listener
Avoid Resonance	Barriers	Enclosure listener
Relocate source/space planning	Mufflers	Hearing Protection
Remove noise source	Absorptive treatment	Masking
Use quitter model	Vibration isolation	
Redesign source to be quitter	Active noise control	

The source-path-receiver model of noise control was first recommended by Bolt and Ingard in 1965 (Rossing, 2007). This model has been approved as a very useful way to represent noise problems. The most effective one to control the noise is by treating the noise source directly. It consequently helps to reduce noise level at the receiver. However it is not always feasible to be implemented, in practical. Maintenance factors such as redesign, redevelop, retool and also costs should be taken into consideration. Control noise at the receiver is the least concern since each receiver must be treated individually (Kutthruf, 1991). Noise control option is limited by controlling the transmission path by using acoustic materials, in this case sound absorbing material (Kidner and Hansen, 2008).

Sound absorbing material is effective in reducing noise level within the space by converting sound wave into heat. Various sound absorbing materials with variety of colours, shapes, and sizes are already in the market places. They are not only providing the desired acoustical properties but also thermal conductivity and flammability. Most of available sound absorbing materials are fibrous materials. Conventionally, synthetic fibers such as fiberglass, glass wool or rock wool are chosen as raw material. These materials offer good acoustical performance nevertheless they are quite expensive and are not sustainable (Nick *et al.*, 2002). The environmental concerns over the use of synthetic fiber for acoustical material have enhanced the demand for an alternative material. For that reason, some researchers showed their great interest in developing alternative sound absorber from recycled materials, such as textile, plastics, foam, or rubber (Paulain *et al.*, 2006; Stankevicious *et al.*, 2007 and Zhou *et al.*, 2007). Even products made from recycled material are welcomed, it is not correlated with ecological issue that required low cost and environmentally friendly material. End of life disposal strategies and environmental friendly technologies for their recycling become a great concern of material development. Indeed, as acoustical panel applied for interior finishes, the performance involving durability as exposed to typical environmental condition, water and extreme temperature, are important of considerations.

1.2 Problem Statement

Regarding to environmental concerns, material developer has looking for natural fiber. The low cost, abundance, weightless, and biodegradable makes natural fibers an attractive material considered for sound absorbers (Zulkifli *et al.,* 2010). Several researches and investigations on natural fibers for sound absorbing material development have been reported. It includes the utilization of bamboo (Kai, 2005), kenaf (Tormos, *et al*., 2007), paddy straw (Mediastika, 2007; 2008), jute (Haryanto, 2008), aspen-wheat- barley straw (Saadatnia, *et al*., 2008), coconut coir (Zulkifli *et al.,* 2008-2011), palm oil (Zulkifli *et al.*, 2008), tea-leaf waste(Ersoy and Kucuk, 2009), sugar-cane (Ismail *et al.*, 2010), rami (Chen *et al.*, 2010), and jute felt (Fatima and Mohanty, 2011). The main significant findings with these natural fibers are due to its superior to synthetic fiber with better electrical resistance, mechanical, thermal and acoustical properties. Therefore, natural fibers can be considered as a good potential replacement to substitute commercially synthetic-product based on advanced material manufactures (Joshi *et al.*, 2004). On the other hand, natural fiber panel has poor durability properties when expose to such environmental condition. Therefore, a material with high strength and durability is obviously needed.

Arenga Pinnata fiber, known as ijuk, is a tough-black-fiber that directly obtained from the trunk of sugar palm. Since last decade, ijuk has been extensively used for a number of products such as broom, brushes, mat, water filter, decoration, rope, roof, and many others (Mogea *et al.*, 1991). The attractive features of *Arenga*

Pinnata fibers are low cost, strong and durable in any typical environment condition such as wet, humid, and extreme temperature (Florido and de Mesa, 2003). Regarding to features offered, *Arenga Pinnata* fibers are appropriate for an alternative engineering material.

Previous investigation by Sastra *et al.,* (2005) confirmed that *Arenga Pinnata* fibers are applicable for composite material component. Composite made from woven roving *Arenga Pinnata* fiber demonstrated high flexural strength. Furthermore, a single *Arenga Pinnata* fiber has moderate tensile strength that almost similar to coir, kenaf, bamboo and hemp fibres (in the range of 138.7 – 270 MPa). *Arenga Pinnata* fibre has high strain strength and flexible compared to others (Bachtiar *et al*., 2010). Owing to its mechanical and physical properties, *Arenga Pinnata* fibers are flexible to be used in broadly engineering applications. Very recently, Sarwidi (2011) stated that *Arenga Pinnata* fibers can be used as vibration insulator for vertically earthquake. It is also used for sound proofing in theater and recording studio. Unfortunately, there is lack of information on acoustical properties of *Arenga Pinnata* fibers. Therefore, more research and finding on acoustical properties of *Arenga Pinnata* fiber must be identified.

1.3 Research Questions

Based on explanation above, some important questions are given:

1. Is *Arenga Pinnata* fibers feasible to be applied for acoustical panel component?
2. If so, what is their acoustical property of *Arenga Pinnata* panel?
3. What is their physical property and how is its influence on acoustical properties of *Arenga Pinnata* panel?
4. How durable is *Arenga Pinnata* panel as exposed to typical environmental conditions including water and extreme temperature?

1.4 Research Objectives

The aim of this research is to investigate the feasibility of *Arenga Pinnata* fiber to be employed as acoustical panels component. To achieve this aim, several objectives have been described as follows:

1. To determine the acoustical properties of *Arenga Pinnata* fibers panel.
2. To obtain the physical properties of *Arenga Pinnata* fibers panel and investigate its effect on its acoustical properties of *Arenga Pinnata* fibers panel.
3. To identify the durability of *Arenga Pinnata* fibers panel as exposed to typical environmental conditions including water and extreme temperature.

1.5 Scope of Research

The scope of the study is limited to:

1. The samples are made from *Arenga Pinnata* natural fiber reinforced binders; Polyurethane (PU), Urea Formaldehyde (UF), and Latex.
2. The weight percentages of fiber and binder are 90%:10%, 85%:15%, 80%:20%, 75%:25%, and 70%:30%.
3. The physical properties determined are density, porosity, and tortuosity.
4. The acoustical properties determined are sound absorption coefficient (α), noise reduction index (NRC), sound transmission loss (STL), and sound transmission class (STC).
5. The durability properties determined are hardness, moisture resistant, water resistant, heat and fire resistant.

1.6 Thesis Outline

This section gives a brief summary of the thesis layout. The thesis is organized in five chapters with the following scopes. Chapter one introduces the research topics, which includes background, objective and scope of research.

Chapter two gives a comprehensive literature review about the acoustical properties of material. Definition, theory, and related work outcomes related to the research are elaborated in chapter two. Two common methods, reverberation room and impedance tube method, often used to measure the acoustical properties is also explicated.

Chapter three presents research methodology including material preparation, sample production, and experimental work. Measurement techniques to evaluate acoustical properties of specimens presented in this chapter.

The results of experimental work including physical, acoustical, and durability properties of panel reinforced with *Arenga Pinnata* fiber are presented in chapter four. The influence of density, porosity, and turtuosity on acoustical properties of samples is discussed in this chapter. The performance of panel including durability and resistance is also explained in detailed.

Chapter five pointed out the conclusion of research. Some further works or recommendations are also presented in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Acoustics

Acoustics is defined as the scientific study of sound, which revolves around the generation, transmission and effect. Sound is generated by a vibrating surface causing pressure variations in an elastic medium that is called a wave (Hansen, 2004). The more elastic a substance, the better it is able to conduct sound waves. The best example is steel, which is highly elastic and an excellent sound conductor.

Sound propagates in the air, water or building material with a certain velocity, normally 344 m/s in the air. Two principal parameters must be aware of when dealing with any acoustics concerns that are frequency and wavelength. Frequency, f, is measured as the number of waves that occur per second and measured in terms of hertz (Hz). Wavelength, λ, is the distance of wave propagation along the medium in one complete wave cycle. These two measures express the nature of pressure variation in a medium that are experienced as sound in the brain. The human ear can detect sounds ranged from approximately 20 to 20,000 Hz but most sensitive in frequency range 500 Hz to 4000 Hz. This upper limit tends to decrease with age. Sound of frequencies below 500 Hz and above 4000 Hz cannot be perceived as sound in the ear but can be felt as vibration in human bodies.

Frequency has inverse relationship to wavelength. They are related to each other through the velocity of sound, v, which points out the direction and time of sound travel to reach listeners. Wavelength is increased as frequency decreased, and conversely as shown in equation 2.1.

REFERENCES

Alessandro, D. F. and Pispola, G. (2005). Sound Absorption Properties of Sustainable Fibrous Materials in an Enhanced Reverberation Room. *The Congress and Exposition on Noise Control Engineering.* Brazil.

Arenas, P. J and Crocker, M.J. (2010). Recent Trends in Porous Sound Absorbing Material. *Material References Issue, 13*. 12-17.

Atmaca, E., Peker, I, and Altin, A. (2005). Industrial Noise and Its Effects on Humans. *Polish Journal of Environmental Studies, 14(6).* 721-726.

Ayoub, M., Nor, M.J.M., Amin, N., Zulkifli, R., Fouladi, M.H., and Ismail, A.R.I. (2009). Analysis on Sound Absorption of Natural Coir Fiber Using Delany-Bazley Model. *Proceedings of the Conference on Mechanical Engineering (ICME2009).* Bangladesh: December 26-28.

Bachtiar,D., Sapuan, S.M. and Hamdan, M.M. (2008). The Effect of Alkaline Treatment on Tensile Properties of Sugar Palm Fibre Reinforced Epoxy Composites. *Materials & Design 29,* 1285–1290.

Bachtiar, D., Sapuan, S.M., Zainudin, E.S., Khalina, A. and Dahlan, K.Z.M. (2010). The TensileProperties of Single Sugar Palm (*Arenga Pinnata*). *Materials Science and Engineering 11 (2)*.

Badri, K and Amin, K.A.M. (2006). Biocomposites from Oil Palm Resources. *Journal of Oil Palm Resources*, 103-113.

Ballagh, K. O. (1996). Acoustical Properties Of Wool. *Applied Acoustics, 48 (2),* 101-120.

Bilova, M. and Lumnitzer, E. (2010). Evaluation of the Acoustic and Non-Acoustic Properties of Sound Absorbing Materials Using a Three-Microphone Impedance Tube. *Applied Acoustics, 71,* 506–509.

Biot, M.A. (1962). Generalized Theory of Acoustic Propagation in Porous Dissipative Media. *Journal of The Acoustical Society of America, 34(5) I*, 1254-1264.

Blomkvist,V., Eriksen, C. A., Theorell, T., Ulrich, R., and Rasmanis, G.(2005). Acoustics and Psychosocial Environment in Intensive Coronary Care. *Occupation Environment Medical, 62*, 1-8.

Castagneade, B., Aknine, A., Brouard, B., and Tarnow, V. (2000). Effects of Compression on The Sound Absorption of Fibrous Materials. *Applied Acoustics, 61*, 173-182

Chao, N. W. and Jiunn, H. T. (2001). Experimental Study of The Absorption Characteristics Of Some Porous Fibrous Materials. *Applied Acoustics, 62,* 447-459.

Chen, D., Li, J., and Ren, J. (2010). Study on Sound Absorption Property of Rami Fibre Reinforced Poly(L-Lactic Acid) Composites: Morphology and Properties. *Composites: Part A 41*, 1012-1018.

Cortis, Smeulders, D.M.J., Lafarge, D., Firdaouss, M., and Guer, J.L. (2001). Geometry Effects on Sound in Porous Media. *IUTAM Symposium on Theoretical and Numerical Methods in Continuum Mechanics of Porous Materials.* Netherlands: Kluwer Academic Publishers.

Cowan, J. P. (1994). *Handbook of Environmental Acoustics.* New York : ITP Van Nostrand Reinhold.

Cox, T.J. and Antonio, J. D. (2004). *Acoustics Absorbers and Diffusors.* London: Spon Press Taylor & Francis Group.

Crocker, M. J. (1998). *Handbook of Acoustics.* Canada: A Wiley-Interscience.

Egan, M. D. (1988). *Architectural Acoustics.* New York: McGraw-Hill.

Ersoy, S. and Kucuk, H.(2009). Investigation of Industrial Tea Leaf Fibre Waste Material for Its Sound Absorption Properties. *Applied Acoustics*, *70*, 215-220.

Fatima, S. and Mohanty, A.R. (2011). Acoustical and Fire Retardant Properties of Jute Composite Materials. *Applied Acoustics,* 72, 108-114.

Florido, H.B. and de Mesa, P.B. (2003). Sugar Palm [Arenga pinnata (Wurmb.)]. *Research Information Series on Ecosystems, 15(2).*

Fouladi , M.H., Nor, M.J.M., Ayub, M.D., Leman, Z.A. (2010). Utilization of Coir Fiber in Multilayer Acoustic Absorption Panel. *Applied Acoustics,7,* 241–249.

Hansen, C. H. (2004). *Fundamentals of Acoustics*. Adelaide University: Lecture Note, 23-53.

Hansen, C. H. and Goelzer, B.I.F. (2006). *Engineering Noise Control.* Adelaide University: Lecture Note, 10.

Haryanto, T. (2007*). Effect of Fibre Ratio on Acoustic Properties and Compressive Strength of Polyester - Ramie (Jute) Fibre Composite*. Institute of Sepuluh November: Undergraduate Theses.

Ismail, L., Ghazali, M.I., Mahzan, S., Zaidi, A.M.A (2010). Sound Absorption of *Arenga Pinnata* Natural Fiber.*World Academy of Science, Engineering and Technology*, 67. 804-806.

Jacobsen, F., Poulsen, T., Rindel, J.H., Gade, A.C., and Ohlrich, M. (2010). *Fundamentals of Acoustics and Noise Control.* Technical University of Denmark: Note no 31200.

Joshi, S.V., Drzal, L.T., and Mohanty, S.A. (2003).Are Natural Fiber Composites Environmentally Superior to Glass Fiber Reinforced Composites?. *Composites: Applied Science and Manufacturing, 35*. 371-376.

Kidner, M. R.F. and Hansen, C. H. (2008). A Comparison and Review of Theories of The Acoustics of Porous Materials. *International Journal of Acoustics and Vibration, 13(3)*, 111-119.

Kim, S.R. and Kim, Y.N. (2004). Broadband Sound Absorption by Helmholtz Array Panel; Its Physical Phenomena and Theory. *The 33rd International Congress and Exposition on Noise Control Engineering.* Prague: August 22-25.

Kinsler, L.A. (1980). *Fundamentals of Acoustics 3rd Edition.* California: John Wiley & Son.

Knapen. E, Lanoye. R, Vermeir. G and Van G. D. (2003). Sound Absorption By Polymer-Modified Porous Cement Mortars. *6th International Conference on Materials Science and Restoration*. MSR-VI Aedificatio Publishers, 347–358.

Kruger, J.and Quickert, M. (1997). Determination of Acoustic Absorber Parameter in Impedance Tubes. *Applied Acoustics, 50,* 79-89.

Kuttruff, H. (1991). *Room Acoustics.* England: Elsevier Science Publishing.

Long, M. (2006). *Architectural Acoustics.* California: Elsevier Academic Press.

Mediastika, C. E. (2007). Potential of Paddy Straw as Material Raw of Acoustic Panel. *Architectural Dimension*, 35(2). 183-189.

Mediastika, C. E. (2008). Paddy Straw as Walling Panel*, Architecture Dimension, 36(1),* 20-27.

Mogea, J., Seibert J. B., Smiths W.(1991) Multipurpose Palms: The Sugar Palm (*Arenga pinnata* (Wurmb) Merr.) *Agrof Sys, 13,* 111-129.

Nick, A., Becker, U. and Thoma, W. (2002). Improved Acoustic Behavior of Interior Part of Renewable Resources in the Automotive Industry. *Journal of Polymers and The Environment, 10 (3),* 115-118.

Nor, M.J.M., Jamaludin, N., Tamiri, F.M. (2004). A Preliminary Study of Sound Absorption Using Multi-Layer Coconut Coir Fibers. *Electronic Journal Technical Acoustics,* 3, 1-8.

Oldfield, R. (2006). *Improved Membrane Absorber*. Salford University: Master Theses.

Paulain, N., Legeais, V., Roualt, E., Parmentier, D., Boccaccio, G., Dorget, M., and Roux, J.C.L. (2006). Development of an Acoustic absorbent Material Using Scrap Tires. *CTTM-IRC.*

Rahman, M.R., Islam, M.N., Huque, M.M., Hamdam, S., Ahmed, A.S. (2010). Effect of Chemical Treatment on Rice Husk (RH) Reinforced Polyethylene (PE) Composites. *BioResources 5(2)*, 854-869.

Ramis, J. Alba, J., Rey, L.D., Escuder, E., and Sanchís V.J. (2010). New Absorbent Material Acoustic Based on Kenaf Fibre. *Materiales de Construcción, 60 (299),* 133-143.

Rashdi, A.A.A., Sapuan, S.M., Ahmad, M.M.H.M., and Khalina, A. (2009). Water Absorption and Tensile Properties of Soil Buried Kenaf Fiber Reinforced Unsaturated Polyester Composites (KFRUPC). *Journal of Food, Agriculture & Environment*, *7 (3&4),* 908-911.

Rossing, T.D. (2002). *The Science of Sound.* USA: Addison Wesley.

Rossing, T. D. (2007). *Handbook of Acoustics.* New York: Springer.

Saadatnia, M., Ebrahimi, G., and Tajvidi, M. (2008). Comparing Sound Absorption Characteristic of Acoustic Boards Made of Aspen Particles and Different Percentage of Wheat and Barley straws. *17th World Conference on Nondestructive Testing*. Shanghai: October 25-28.

Sabri. (2007). *Evaluation of the Acoustical Performance of Natural Fiber as Alternative Material to Control Noise.* Institute of Technology Bandung: Masters Theses.

Saeki, T., Fujii, T., Yamaguchi, S., and Harima, S. (2004). Effects of Acoustical Noise on Annoyance and Performance Fatigue During Mental Memory Task. *Applied Acoustics 65,* 913–921.

Sagartzazu, X., Nieto, L.H., and Pagalday, J.M. (2008). Review in Sound Absorbing Materials. *Architectural Computational Methods Engineering*, *15,* 311-342.

Sakagami, K., Kiyama, M., Marimoto, M., and Takahashi, D. (1996). Sound Absorption of a Cavity-Backed Membrane: A Step Towards Design Method for Membrane-Type Absorbers. *Applied Acoustics, 49(3),* 231-241.

Sarwidi (2011). *Tentang Ijuk: Lagi-Lagi Ijuk Bisa Jadi Bahan Untuk Bangunan Rumah Anti Gempa*. Http://arengabroom.blogspot.com.

Sastra, H.Y., Siregar, J.P., Sapuan, S.M., Leman, Z. and Hamdan, M.M. (2005). Flexural Properties of *Arenga Pinnata* Fibre Reinforced Epoxy Composites. *American Journal of Applied Sciences*, *21-24,* ISSN 1546-9239.

Sheddeq, H. S. (2009). Factors Influencing Acoustic Performance of Sound Absorptive Materials. *Australian Journal of Basic and Applied Sciences*, *3(4)*, 4610-4617.

Sides, DJ, Attenborough, K, Mulholland, K.A. (1971). Application of a Generalized Acoustic Properties Theory to Fibrous Absorbers. *Journal of Sound and Vibration (1),* 49-64.

Siegesmund, S. and Snethlage, R. (2011). *Stone in Architecture*: *Properties, Durability*. Springer.

Sitepu, M., Christiani, E.S., Sembiring, M., Barus, D., and Sudiati (2006). Modifikasi Serat Ijuk dengan Radiasi Sinar – γ Suatu Studi untuk Perisai Radiasi Nuklir. *Jurnal Sains Kimia, 10(1),* 4–9.

Stankevicius, V., Skripkiunas, G., Grinys, A., and Miskinis, K. (2007). Acoustical Characteristics and Physical – Mechanical Properties of Plaster with Rubber Waste Additives. *Material Science*, *13 (4).*

Strong, A.B. (1999*). Flammability Testing*. Brigham Young University.

Sun, F., Chen, H., Wu, J., and Feng, K. (2010). Sound Absorbing Characteristics of Fibrous Metal Materials at High Temperatures. *Applied Acoustics, 71*, 221–235.

Taib, R. M., Ramarad, S., Ishak, Z.A.M., and Todo, M. (2008). Water Absorption and Tensile Properties of Kenaf Bast Fiber-Plastisized Poly(Lactic Acid) Biocomposites. *Proc. of The Polymer Processing Society 24th Annual Meeting.* Italy.

Thompson, D.J., Gardonio, P. and Rohlfing, J. (2009). Can a Transmission Coefficient be Greater Than Unity?. *Applied Acoustics, 70,* 681-688.

Ticoalu, A., Aravinthan, T., and Cardona, F. (2011). Experimental Investigation into Gomuti Fibres/Polyester Composites. *Incorporating Sustainable Practice in*

Mechanics of Structures and Materials – Fragomeni, Venkatesan, Lam & Setunge (eds). London: Taylor & Francis Group. ISBN 978-0-415-61657-7.

Tormos, D. R., Romina, Fernandez, A., Jesus, and Vicente, S. (2007). Proposal an Empirical Model for Absorbent Acoustical Materials Based in Kenaf. *19th International Congress on Acoustics.* Madrid. (1-6).

Umnova, O., Attenborough, K., Ho, C.S., and Cummings, A.(2005).Deduction of Tortuosity and Porosity from Acoustic Reflection and Transmission Measurements on Thick Samples of Rigid-Porous Materials. *Applied acoustics 66*, 607–624.

Vissamraju, K. (2005). *Measurement of Absorption Coefficient of Road Surfaces Using Impedance Tube Method* . Auburn University, Alabama: Masters Thesis.

Wahyuni, N. (2010). *Pemanfaatan Serat Ijuk Pendek Dalam Pembuatan Beton Ringan dan Karakteristiknya.* University of North Sumatera: Undergraduate Thesis.

Wassilieff, C. (1996). Sound Absorption of Wood-Based Materials. *Applied Acoustics, 48(4),* 339-356.

Xu, J.,Sugawara, R., Widyorini, R., Han, G., and Kawai, S. (2004). Manufacture and Properties of Low-Density Binderless Particleboard from Kenaf Core. *The Japan Wood Research Society, 50*, 62-67.

Xu, M.B, Selamet A., and Kim, H.(2010). Dual Helmholtz Resonator. *Applied Acoustics,*71, 822–829.

Yousefi, H. (2009). Canola Straw as a Bio-Waste Resource For Medium Density Fiberboard (MDF) Manufacture. *Waste Management*, *29*, 2644-2648.

Zhou, H., Bo, L., Guangsu, H., and Jia, H. (2007). A Novel Composite Sound Absorber with Recycled Rubber Particles. *Journal of Sound and Vibration, 304,* 400-406.

Zulkifli, R., Nor, M.J.M., Tahir, M.F.M., Ismail, A.R., and Nuawi, M.Z. (2008). Acoustic Properties of Multi-Layer Coir Fibres Sound Absorption Panel. *Journal of Applied Sciences*, *8(20)*, 3709-3714.

Zulkifli, R., Nor, M.J.M., Ismail, A.R., Nuawi, M.Z., and Thahir, M.F.M. (2009a). Effect of Perforated Size and Air Gap Thickness on Acoustic Properties of Coir Fibre Sound Absorption Panels. *European Journal of Scientific Research, 28(2)*, 242-252. *ISSN 1450-216X.*

Zulkifli, R., Nor, M.J.M., Ismail, A.R., Nuawi, M.Z., Abdullah, S., Thahir, M.F.M., and Rahman, M. N.A. (2009b). Comparison of Acoustic Properties between Coir Fibre and Oil Plam Fibre. *European Journal of Scientific Research, 33*, 144-152. *ISSN 1450-216 X.*

Zulkifli, R., Zulkarnain and Nor, M.J.M. (2010). Noise Control Using Coconut Coir Fiber Sound Absorber with Porous Layer Backing and Perforated Panel. *American Journal of Applied Sciences, 7(2),* 260-264. *ISSN 1546-9239.*